

Lateral drainage design update—Part 2

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Part 1 of this series established the need to design lateral drainage systems for unconfined flow, i.e., flow such that the maximum liquid thickness is less than the thickness of the lateral drain. Methods for evaluating the maximum liquid thickness in natural or geosynthetic lateral drains were presented. Additionally, Part 1 demonstrated that the following current practices are wrong: equivalency of natural to geosynthetic lateral drainage layers, which cannot be based on equal transmissivity, and the use of a weighted permeability to evaluate the performance of natural over geosynthetic lateral drainage systems, which is incorrect and non-conservative.

Part 2 will demonstrate the benefits of optimizing the lateral drainage system to maintain parallel flow oriented perpendicular to contour lines. Part of this demonstration will challenge regulatory concepts regarding leakage detection systems. Part 2 will also review minimum testing requirements in conjunction with development of long-term service reduction factors.

Optimizing the lateral drainage system

During the past decade, the authors have reviewed many lateral drainage systems that had marginal performance because the designers had failed to consider the impact of converging flow lines. The performance of such lateral drainage systems could be greatly enhanced at a nominal cost by the addition of perimeter drainage systems, e.g., toe or pipe drains. The benefits of parallel flow are demonstrated here by showing the impact of optimization on the action leakage rate (ALR) of a leakage detection system (LDS) located between the primary and secondary liners of a double liner system. The simple concept presented in this application is applicable in all lateral drainage systems.

The LDS system monitors the performance of the primary liner and limits the head acting on the secondary liner. The ALR is defined in 40 CFR 265.302 as the maximum flow rate that the leakage detection system can remove without the fluid head on the bottom liner exceeding 30 cm. This limit was based on a lateral drainage system using sand or gravel and was intended to define the flow rate at which a limited portion of the system became saturated. Note that this is consistent with the goal of unconfined flow within the lateral drainage system. In the case of lateral drainage systems whose thickness is less than 30 cm, such as geocomposites, the maximum liquid thickness must be less than or equal to the thickness of the drainage system.

The action leakage rate for parallel flow is calculated by setting the maximum liquid thickness, t_{\max} , equal to the thickness of the lateral drainage system. Recall from Part 1 of this article, the maximum liquid thickness in a granular drainage layer can be calculated using Giroud's solution (see Part 1, **Eq. 1**). For a thin geocomposite drainage layer, the maximum liquid thickness, t_{\max} , is approximated in Part 1 as

Part 1, Eq. 3

$$t_{\max} = \frac{q_h L}{k \sin \beta}$$

where β is the slope angle, q_h is the fluid supply rate assumed to be uniformly distributed over the entire area of the drainage layer, k is the permeability of the drainage media, and L is the slope length measured horizontally. Substituting the maximum flow height of the drainage layer into one of these equations allows solving for the maximum fluid supply rate, $q_{h\max}$, that can flow into the LDS. The ALR is then calculated by applying this fluid supply rate over the area serviced by the LDS, i.e.,

Eq.1

$$ALR = BLq_{h\max}$$

where B is the effective width of the LDS draining to the drainage layer.

For radial flow into a corner sump (**Figure 1**), Giroud and Zhao (2000) showed that the maximum unconfined flow height, t_{rad} , is given as follows:

Eq.2

$$t_{\text{rad}} = \frac{q_h^{\text{rad}} A_{\text{LDS}}}{k \alpha r \sin \beta}$$

where A_{LDS} is the area of the leak detection system ($B L$), r is the equivalent radius of the rectangular sump, and α is the angle in radians serviced by the sump ($\alpha = \pi/2$ for **Figure 1**). As suggested by Giroud and Zhao (2000), the equivalent radius of the rectangular sump is given as:

Eq.3

$$r = 2\sqrt{\frac{ab}{\pi}}$$

where a and b are the dimensions of the rectangular sump.

Setting t_{\max} from Part 1, **Eq.3** equal to t_{rad} in **Eq.2** yields the following:

Eq.4

$$\frac{q_h}{q_h^{\text{rad}}} = \frac{B}{\alpha r} = \frac{2B}{\pi r} = \frac{B}{\sqrt{\pi ab}}$$

Typically, this ratio exceeds 10. This means that radial flow systems will begin confined flow at fluid input rates nearly an order of magnitude less than parallel flow systems. The ALR for a radial flow system will therefore also be an order of magnitude less than that of a parallel flow system if all other variables are equal. For this reason, radial flow systems should be avoided! This is true for both the LDS and the primary

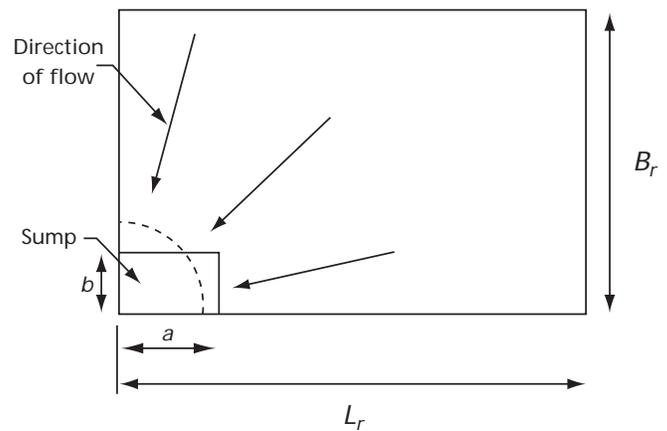


Figure 1: Plan view of a rectangular liquid collection layer with a rectangular sump in the cover.

leachate collection removal system. In cases where radial flow cannot be avoided, practical guidance is provided by Giroud and Zhao (2000).

The reader should also note that the use of a geocomposite drainage component for the LDS system has the advantage of dramatically reducing the head acting on the lower liner under these saturated flow conditions. A sand or gravel LDS will have a 30 cm maximum head compared to an approximate 6 mm head for the geonet alternative. Recalling from Part 1 that a geocomposite drain with a maximum head of 6 mm will have 34 times less leakage than a soil drain having a maximum head of 30 cm. This is significant! Unfortunately, designers commonly focus on the quantity of leachate drained by the LDS system and not the overall reduction in leakage resulting from head reduction.

Laboratory evaluation of properties

The critical engineering properties of a geocomposite drain include:

- In-plane flow capacity (or transmissivity) of the geonet/geocomposite under design loads and boundary conditions,
- Filtration characteristics of the upper geotextile relative to the soil retained or the liquid in question,
- Internal shear strength, and
- Interface friction with adjacent soil and/or geosynthetics.

The in-plane flow capacity of a geocomposite is evaluated using a laboratory transmissivity test (ASTM D 4716). This test is performed using the transmissivity box that allows a range of normal loads and boundary conditions, i.e., soil or geomembrane, to be applied to the face of the geocomposite. The head acting across the 300 mm square sample can be varied to create a range of gradients that simulate field slope conditions. The flow gradient, i , is defined as the head divided by the flow length (300 mm in the case of ASTM D 4716). Typical data produced by this test are shown on **Figure 2**. In general, transmissivity decreases with increasing normal loads and increasing flow gradients. Specific guidelines for minimum test conditions for the transmissivity test are presented in the following section on evaluation of long-term service reduction factors.

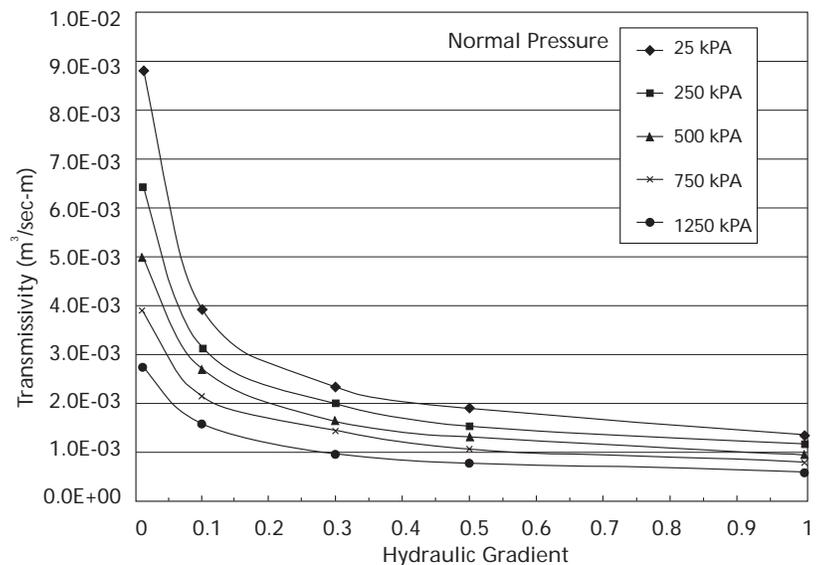


Figure 2: Transmissivity vs. gradients for a triplanar geonet laminated with a 270g/m² nonwoven geotextile on each side with soil as a top boundary and aluminum plate as lower boundary (ASTM D 4716).

Interface friction and internal shear strength tests are critical for a geocomposite that will be used in applications that involve significant slopes. The interface and internal shear strength is evaluated using either the di-

rect shear test (ASTM D 5321) or tilt-table tests not currently standardized. As with the transmissivity test, sample size is commonly 12-in. square and the test equipment allows a range of normal loads and boundary conditions to be applied to the face of the geocomposite.

Long-term service reduction factors

Lateral drainage systems may degrade with time due to the very liquids they carry and the normal loads they are subjected to. A geocomposite must have sufficient flow capacity under the conditions that exist in the field during the entire design life of the liquid collection layer. Thus, the designer must provide surplus hydraulic capacity in the lateral drain to ensure that flow within the lateral drain remains unconfined during the design life of the system. The discussion in this section is intended to provide the reader with a background in the various service reduction factors used to quantify this degradation. Many of these factors can be quantified during laboratory testing of the geocomposite. However, many factors require significant judgement on the part of the designer. Such judgement must be tempered by the criticality of the application and the impact of potential failure.

The long-term-in-soil transmissivity of the drainage geocomposite, θ_{LTIS} , was initially quantified by Koerner (1998) as follows:

Eq.5

$$\theta_{LTIS} = \frac{\theta_{\text{measured}}}{RF_{IN} * RF_{CR} * RF_{CC} * RF_{BC}}$$

where θ_{measured} is the transmissivity measured in accordance with ASTM D-4716, and the *RFs* are service reduction factors described as follows:

RF_{IN} = reduction factor for elastic deformation, or intrusion of the adjacent geotextiles into the drainage channel.

RF_{CR} = reduction factor for creep deformation of the drainage core and/or adjacent geotextile into the drainage channel.

RF_{CC} = reduction factor for chemical clogging and/or precipitation of chemicals in the drainage core space.

RF_{BC} = reduction factor for biological clogging in the drainage core space.

More recent work by Giroud, Zornberg and Zhao (2000) has defined additional reduction factors that include the following:

RF_{IMCO} = reduction factor for immediate compression, i.e., decrease of hydraulic transmissivity due to compression of the transmissive core following immediately the application of stress.

RF_{IMIN} = reduction factor for immediate intrusion, i.e., decrease of hydraulic transmissivity due to geot-

extile intrusion into the transmissive core immediately following the application of stress.

RF_{CD} = reduction factor for chemical degradation, i.e., decrease of hydraulic transmissivity due to chemical degradation of the polymeric compound(s) used to make the geocomposite.

RF_{PC} = reduction factor for particulate clogging, i.e., decrease of hydraulic transmissivity due to clogging by particles migrating into the transmissive core.

Each reduction factor corresponds to a mechanism that reduces the hydraulic transmissivity of the geocomposite in the field. If one of these mechanisms occurs during the hydraulic transmissivity test in the laboratory to the same extent as in the field, then the corresponding reduction factor is equal to 1.0. An ideal hydraulic transmissivity test would perfectly simulate in the laboratory all the mechanisms that reduce the hydraulic transmissivity in the field such that all reduction factors would be equal to 1.0. However, such a test is not achievable from a practical standpoint, because it would be extremely complex and would require a very long time.

Evaluation of service reduction factors

This section discusses what is currently known regarding service reduction factors. This information is currently not incorporated into ASTM D 4716. RF_{IMCO} , RF_{IMIN} , RF_{CR} , and RF_{IN} , result from mechanical mechanisms, i.e., they are directly related to the applied stress. In contrast, RF_{CD} , RF_{PC} , RF_{CC} , and RF_{BC} result from physico-chemical mechanisms and, as such, they are not directly related to the applied stress. The physico-chemical mechanisms do not occur during hydraulic transmissivity tests that are performed with pure water. In contrast, the mechanical mechanisms may occur (at least to a certain degree) during the hydraulic transmissivity test.

RF_{IMCO} and RF_{IMIN} correspond to instantaneous mechanisms (i.e., mechanisms that take place as soon as the stress is applied), whereas the other reduction factors correspond to time-dependent mechanisms. RF_{IMCO} can be

Examples of application	Normal stress	Liquid	RF_{IN}	RF_{CR}	RF_{CC}	RF_{BC}
Landfill cover drainage layer, Low retaining wall drainage	Low	Water	1.0–1.2	1.1–1.4	1.0–1.2	1.2–1.5
Embankment, Dams, Landslide repair, High retaining wall drainage	High	Water	1.0–1.2	1.4–2.0	1.0–1.2	1.2–1.5
Landfill leachate collection layer, Landfill leakage collection and detection layer, Leachate pond leakage collection and detection layer	High	Leachate	1.0–1.2	1.4–2.0	1.5–2.0	1.5–2.0

Notes: **Table 1** was developed using reduction factor values from Koerner (1998). Design engineers are cautioned that the values of the reduction factors may significantly vary depending on the type of geocomposite and the exposure conditions (stress, chemical composition of the soil and liquid). Also, RF_{IN} and RF_{CR} depend on the testing conditions under which the hydraulic transmissivity is measured. The reduction factor values given in **Table 1** correspond to the case where the seating time is of the order of 100 hours or more and the boundary conditions due to adjacent materials are simulated in the hydraulic transmissivity test. Finally, due to lack of relevant data, no guidance is provided for RF_{CD} and RF_{PC} .

Table 1: Guidance for the selection of some reduction factors on the flow capacity of geonets and geocomposites having a geonet transmissive core (after Giroud, Zornberg and Zhao 2000).

eliminated (i.e., $RF_{IMCO} = 1.0$) if the hydraulic transmissivity is measured after a stress equal to, or greater than, the stress in the soil is applied to the specimen of transmissive material subjected to the hydraulic transmissivity test. RF_{IMIN} can be eliminated (i.e., $RF_{IMIN} = 1.0$) if the hydraulic transmissivity test simulates the boundary conditions created by the presence of materials adjacent to the transmissive material.

The determination of RF_{CR} , RF_{IN} , RF_{CD} , RF_{PC} , RF_{CC} and RF_{BC} requires long-duration tests. RF_{CR} and RF_{IN} can be decreased if the hydraulic transmissivity is measured after the stress has been applied for a certain period of time (seating time). During seating, part of the creep of the transmissive core and part of the delayed intrusion would have occurred before the hydraulic transmissivity is measured. The test boundary conditions must replicate actual field service conditions. For instance, the upper boundary for a surface-water removal layer in landfill covers and the leachate-collection layer in landfill liners is either a vegetative supporting soil layer or a drainage/protection layer. The appropriate overlying material must be included in the transmissivity test to properly simulate the intrusion of the geotextile into the geonet and the resulting loss of transmissivity.

The recently published GRI-GC8 standard (2001) requires the allowable transmissivity being determined under simulated conditions for 100-hour duration. No long-term intrusion reduction factor beyond 100-hour duration is considered. Creep reduction factor RF_{CR} is based on 10,000-hour compressive creep data and calculated according to formulas developed by Giroud, Zhao and Richardson (2000). Compared to those reduction factors in Table 1, RF_{CC} those recommended by GRI is similar, RF_{BC} is higher for landfill caps, and lower for LCS and LDS. **Figure 3** presents the long-term transmissivity test data for a triplanar geonet composite tested under in-soil condition and normal load of 720 kPa (15,000/ft.²).

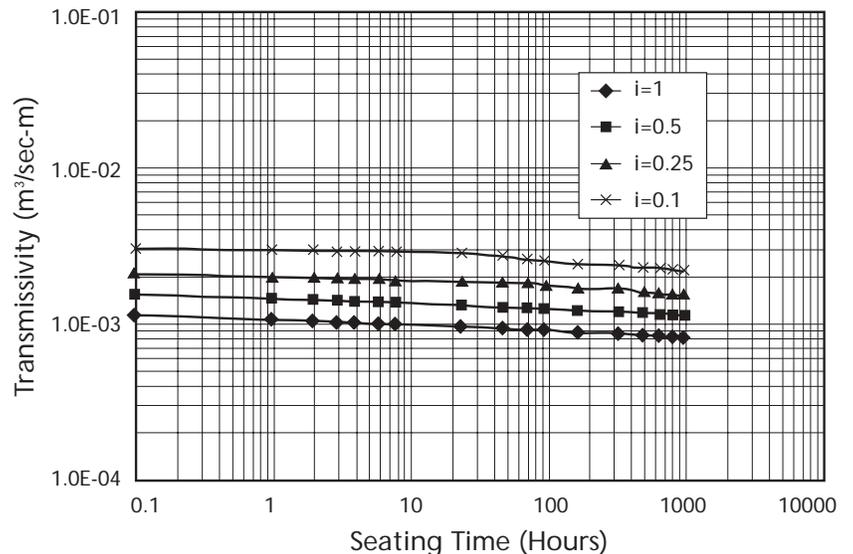


Figure 3: Long-term transmissivity for a triplanar geocomposite (with soil boundary, 270 g/m² nonwoven each face, normal load =720 kPa, 15,000/ft.²).

Finally, it should be noted that the various reduction factors may not be completely independent. For example, chemical degradation may affect creep resistance (i.e., may increase RF_{CR}), and, as shown by Palmeira and Gardoni (2000) for a nonwoven geotextile used by itself as a drainage medium, the presence of soil particles in a needle-punched nonwoven geotextile (i.e., particulate clogging) may reduce the geotextile's compressibility (i.e., it may reduce RF_{IMCO} and RF_{CR} while increasing RF_{PC}). Also note that not all the reduction factors are discussed, for instance, root penetration into geonet.

In the absence of site-specific testing data, the authors recommend the upper limits of the above default

values for RF_{IN} , RF_{CC} , and RF_{BC} for landfill covers, average default values for leachate collection systems, and lower limits for leakage detection systems. This reflects the service life of the final cover, the potential for significant compressive creep or intrusion of the leachate collection systems, the large quantity of leachate to be handled by the leachate collection system, and the expected lower level of intrusion and leachate volume to be conveyed by the leakage detection system.

Reduction factor for creep, RF_{CR} , should be determined in accordance with GRI-GC8. In the absence of 10,000-hour creep data, designers must assess the applicability of the geocomposite with respect to structural stability under loads. As a minimum, upper limits of the default values should be used.

Be aware that reduction factors discussed above are not factor-of-safety. A factor-of-safety should be used in all calculations to take into account possible uncertainties in the selection and determination of design parameters. FS values of 2–3 are recommended for drainage design by Giroud, Zornberg and Zhao (2000). A recent article (Koerner 2001) indicates the following FS values for geosynthetic engineering:

- Filtration and drainage: $FS > 10$
- Puncture of geomembrane: $FS > 3$
- Reinforced walls and slopes: $FS > 2$.

Closure

With the increased interest in landfill “bioreactors,” it will be a challenge for designers to maintain control over drainage. It is hoped that these articles will encourage the proper design of lateral drainage systems and end a number of regulatory myths. Lateral drainage systems must be designed and not sized based on regulatory minimums. Limiting the head acting on the liner should be a goal as important as minimizing defects of the liner during installation.

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